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Basic complexity criteria and their impact on manual assembly quality in actual production

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ABSTRACT

Increasing design and assembly complexity are challenges facing the automotive industry today because increasing number of car variants and build options can result in immense difficulties and lead to costly assembly errors and quality losses. In order to remain on the market these conditions must nevertheless be managed by companies in hard competition with other manufacturers.

The objective of this study was to analyze the impact of newly developed basic complexity criteria (CXB) on assembly quality and associated costs for corrective measures in manual assembly of cars. Data on error rate and action costs of assembly tasks of different complexity level was collected and analyzed. The inter-relationship between different complexity criteria was analyzed to see whether any criteria had a greater impact than others.

The results showed that the action costs/car increased with increasing complexity level and that several complexity criteria together resulted in increased action costs. Some criteria tended to have a greater impact than others but need more research. The results further suggest that if high complexity issues are identified and replaced by low complexity solutions the assembly related action costs in manual assembly are likely to decrease.

Relevance to industry: By reduction of basic assembly complexity already in early planning stages in product development significant reduction of costly assembly related action costs in manual assembly can probably be made.

1. Introduction

In order to attract customers today it is crucial for manufacturers to produce high value added products in response to customer demands and expectations at a competitive price. In addition, manufacturers must meet sustainability requirements regarding environmental and social aspects. The challenge facing the industry therefore, are characterized by design complexity that must be matched with a flexible and complex manufacturing system as well as advanced agile business processes to remain competitive (ElMaraghy et al., 2012). As a consequence manufacturers must offer a wide range of continuously improved products at competitive prices in order to maintain and increase their market share, which in turn requires a strong customer adaptation and a high level of cost efficiency at the same time. Lancaster (1990), Schleich et al. (2007) and Orji et al. (2011) concluded that the degree of product variety increases with the market competition and that variety can result in a higher market share and sales volumes but at the same time increases product complexity and cost. This situation in particular applies to the automotive industry and has resulted in frequent model changes and increased number of car variants with more features and functionality to satisfy or even exceed customer's expectations. In a typical assembly plant, the numbers of different vehicles, variants and options can reach ten thousands of combinations of build options and result in enormous difficulties in managing such complex product assortment and assembly conditions (Rekiek et al., 2008; Zhu et al., 2008). This means that the manufacturer that can manage such complex products and installation conditions will have distinct competitive advantages.

There are over 50 different car manufacturers in the world in over 40 countries (OICA, 2014). In Sweden, for example, the vehicle production (cars and trucks) corresponds to less than 1% of the total number of produced vehicles in the world in 2012, which obviously places extra demands on the ability to build complex and high

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quality products at a competitive price.

1.1. The complexity concept

Complexity is a multifaceted concept that is not easily defined and depends on in which context it applies. Several researchers have tried to clarify what complexity means, which has resulted in many different definitions and measurements based on research area, scope and objective. Examples of efforts in defining complexity are e.g. MacDuffie et al. (1996) who proposed three main types of complexity: model-mix complexity, part complexity (parts and components variation) and option content (variations independent of the core design). Frizelle and Woodcock (1995) introduced two fundamental types of complexity: structural (static) complexity and operational (dynamic) complexity. Static complexity is time-independent due to the product and system structure whereas dynamic complexity is time-dependent and deals with the operational behavior of the system. Kuzgunkaya and ElMaraghy (2006) and Rodriguez-Toro et al. (2004) defined static complexity as the structure of the system along with the variety of its components including the strengths of interactions among them. Dynamic complexity accounted for the operational aspects and unpredictability over a time period. Rodriguez –Toro et al. (2002) suggested that complexity can be divided into two main types: component and assembly complexity where component complexity is related to the geometry of components and assembly complexity to the structural breakdown of the product and the number of operations required to assemble a product. However, available complexity models are mainly theoretical and there is no common approach for how to measure complexity according to Orji et al. (2011). By introducing five main dimensions of product complexity based on different complexity sources in product design, development, manufacturing, assembly and supply chain their idea was to develop a unified product complexity metric to be used as a design decision support tool for improvement and systematic management of product complexity in order to control the impact of it. Samy and ElMaraghy (2012) stated that the management of complexity should consider both product and system complexity and presented a complexity dependency matrix for assessing and mapping the complexity of products and their assembly. Samy and ElMaraghy (2012) meant that managing production complexity can help reduce cost and time and thereby increase productivity, quality, profitability and competitiveness. Both Orji et al. (2011) and Cryssoloursis et al. (2013) stated that in order to consider complexity in a system the complexity sources should be measured in quantifiable terms.

1.2. Task complexity

Wood (1986) thought that task complexity influences human performance and behavior by placing demands on task performers. Campbell (1988) meant that a complex task is one that places high demands on the task performer and Liu and Li (2012) meant that task complexity was an important factor influencing and predicting human performance and behavior. Liu and Li (2016) stated that “defining task complexity is a markedly complex task” in itself, which is not simple because there are many aspects of complexity that are not easily defined and described. Task complexity has no general and widely-accepted definition but proposed definitions mirrors the mental images of different researchers. In order to clarify different task complexity aspects Liu and Li (2012) made a review of existing task complexity models that was compared with other models and made an inventory of task complexity definitions. They differed between objective task complexity and subjective task complexity. Objective task complexity refers to the complexity of the task, which is independent of the task performer. A complex task may have many task elements and task elements interconnected with each other. The subjective task complexity is related to the performer's ability. When the complexity of the task exceeds the capacity of the task performer, the performer will perceive the task complex. Many task complexity models conform to this view point, e.g. by Bonner (1994) and Ham et al. (2012). In other viewpoints task complexity seems to be synonymous with task load or task demand (e.g. Sintchenko and Coiera, 2003; Bedny et al., 2012).

1.3. Assembly complexity

The huge amount of variants and build options in automotive assembly offers a challenge in production planning and for the operator who is supposed to manage many different tasks in paced assembly lines.

Zhu et al. (2008) therefore developed evaluation models that measured complexity based on the choices operators need to make at the work station level d in mixed-model assembly systems due to the variety in customers' orders. They found that the more assembly options that were available to the operator, the more assembly-related errors occurred. Several studies recently by Mattson et al. (2012, 2014) have focused on human aspects such as perceived complexity and individual factors. Furthermore, they found that conditions at the work station had to be improved in order to support the operator in building the right quality.

Guimares et al. (1999) proposed that the complexity perceived by the operators is caused by the basic complexity associated with the system and the tasks.

1.4. Basic assembly complexity and complexity criteria

Studies by Falck et al. (2014) had a different approach focusing on how basic[1] assembly complexity, CXB (that could be attributed to objective task complexity) affects operator conditions, productivity and assembly quality. Basic assembly complexity refers to fundamental assembly complexity depending on the design of components and products in early product development phases of new assembly concepts. These fundamental conditions were believed to be crucial for the assembly conditions in the factory. Their research in Swedish automotive industry showed that CXB criteria would have a major impact on assembly conditions and assembly quality in manual assembly.

For assessment of CXB Falck et al. (2014) used complexity criteria that originated from an interview study of assembly ergonomics and assembly complexity in manual work in Swedish manufacturing companies (Falck and Rosenqvist, 2012). 64 very experienced design and manufacturing engineers answered semi-open questions about ergonomics, assembly complexity issues and reasons for errors in manual assembly. Since the concept of assembly complexity was commonly used among engineers they were asked to define and give examples of what characterized high and low assembly complexity issues. A vast number of suggestions were obtained but after analyzing and unifying of very similar or identical descriptions sixteen different criteria remained. It was considered by the researchers that these criteria could be tested for assessment of CXB. They were first applied in a study in car assembly (Falck et al., 2014) where the complexity level of each of 47

[1] Basic assembly complexity (CXB) meaning the basic design of product, components and system solutions developed and decided in early development phases of new cars. Basic complexity criteria include both structural (static) and operational (dynamic) complexity (see above) criteria.